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WEATHER BUREAU.

MISSISSIPPI RIVER LEVEES AND THEIR EFFECT ON RIVER STAGES DURING FLOOD PERIODS.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

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LOCAL FORECASTER.

WASHINGTON:

WEATHER BUREAU.

1910.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., June 7, 1910.

The Honorable,
The Secretary of Agriculture,
Washington, D. C.

SIR: I have the honor to transmit herewith a paper by Mr. Samuel C. Emery, Local Forecaster in charge of the local office of the Weather Bureau at Memphis, Tenn., on "Mississippi River Levees and their Effect on River Stages During Flood Periods."

I recommend the publication of this paper as a bulletin of the Weather Bureau.

Very respectfully, your obedient servant,

WILLIS L. MOORE,
Chief United States Weather Bureau.

Approved.

JAMES WILSON,
Secretary of Agriculture.

MISSISSIPPI RIVER LEVEES AND THEIR EFFECT ON RIVER STAGES DURING FLOOD PERIODS.

The Mississippi River, following its winding course from near Lake Itasca, in northern Minnesota, to the Gulf of Mexico, is about 2,446[1] miles in length. The head waters of its tributaries extend from New York on the east to northern Montana on the west, and its drainage area is 1,242,600 square miles, about two-fifths of the total area of the United States. The river is navigable throughout from St. Paul, Minn., to its mouth, a distance of 1,954 miles. The head of navigation is Cass Lake[2] about 2,380 miles from its mouth, and the total navigable length of the entire system is 13,869[3] miles.

The lower Mississippi River, that portion extending southward from Cape Girardeau, Mo., to the Gulf, a distance of 1,128 miles, flows in a bed composed largely of sedimentary matter deposited by the river itself, and is typically a river with unstable bed, with rapidly caving banks, and shifting bottom. Except where the river strikes one of the bluffs that are found at long intervals south of Cairo, most of which are on the left bank, the banks range in height from about 25 to 40 feet above extreme low water. As the river in times of flood rises to 40 or 50 feet above the low-water line, the banks as well as the low lands lying back of them are consequently subject to overflow. The Mississippi River at all times contains a varying amount of material held in a state of suspension or rolled along the bottom by the motion of the water. When the water in the river becomes unusually agitated, as at flood time, and bank erosion is going on rapidly, the amount of sediment is greatly increased. At an active rising stage the material carried past a given point is said to be equal to 1,000 tons a minute. Now when the amount of water in the river is too great to be contained within its natural banks it flows out over the adjacent lands, where its motion being arrested, the sediment is deposited. Naturally the greater portion of the sediment is dropped near the river bank and the finer and lighter particles are carried farther inland. Thus it comes that the lands nearest the river, by receiving this annual deposit, are slowly built up until they have become considerably higher than those farther toward the interior. This is especially noticeable in the St. Francis and Yazoo basins, where the slope and consequently the drainage, is away from the river instead of toward it as is the case with most rivers.

From St. Louis to the Gulf the river drops 380 feet in a series of alternately reversed bends. In the bends the current impinges on the con-

[1] Annual Report, Chief of Engineers, 1909, p. 2677.
[2] Annual Report, Chief of Engineers, 1909, p. 564.
[3] Preliminary Report of Inland Waterways Commission, 1908, p. 35.

cave bank, causing a deepening of the water along the shore and, in most cases, rapid caving and erosion of the bank. At the foot of each bend the main flow crosses to the other side, impinging on the concave bank on that side, and so back and forth, the place in the channel where this takes place being called a "crossing." In these crossings the current slackens and there results a local deposit of the rolling or suspended material moving with the water which deposit forms a "bar." Thus it happens that there is a shoaling of the river with a bar of some dimensions between every two bends in the river as well as at any point of a straight reach where the river is unusually wide. Some of the bars are not built up sufficiently to obstruct navigation or deflect the current noticeably, while others spread over large areas and rise to within a few feet of the water surface. The bottom of the river, if exposed to view, would show a succession of great sand hills and intervening depressions. It is the tops of the sand hills that form the bars obstructing navigation, and in order to provide navigable depths during periods of low water, the Government maintains a fleet of 10 or 12 powerful hydraulic dredges that cut channels through the bars, discharging the dredged material outside of the channel through a pipe line. These dredges operate between St. Louis and Vicksburg during the low-water months and usually maintain navigable channels throughout the year, except when the river is closed by ice.

The greatest and most fertile portion of the alluvial lands along the Mississippi River between Cape Girardeau and the Gulf being below the level of the flood, the first object of the planter has always been to secure himself against inundation in times of high water. To obtain this immunity the only practical method that has so far suggested itself is to raise the banks high enough to hold all the water and keep the river within certain permanent and prescribed limits. Thus the system of artificial embankments or "levees" as the French called them, came into use at a very early day, and the same system, though greatly improved as regards construction, prevails at the present time. The use of the levee as the sole method of restraining the waters of the Mississippi for the protection of the alluvial lands against the ravages of floods has been in practise since the year 1718, when the first settlement at New Orleans being greatly harassed by high water, began the construction of a levee about 3 feet in height in front of the town. By 1752 levees had been built along the river front 20 miles below and 30 miles above New Orleans. These levees were built by the planters themselves, each building a levee the length of his river front. In 1743 an ordinance was promulgated requiring the inhabitants to complete their levees by the 1st of January, 1744, under penalty of the forfeiture of their lands to the crown. Work progressed slowly up the river during the French and Spanish occupation and even after the Louisiana Purchase in 1803. In 1812 the levee extended a length of 155 miles on the east side of the

river and about 185 miles on the west side. The total length of the levees in 1812 was therefore 340 miles, and it is said that the amount expended in this work was between five and six million dollars. By the year 1828 the line of levees was continuous from Red River Landing to 65 miles below New Orleans, a distance of 260 miles.[1] With the view of aiding the several States bordering the river in the construction of protection levees, the Federal Government in 1850 issued by grant certain swamp lands, which were to be sold by the States and the funds obtained thereby to be applied to levee work and drainage. Though many of these lands were of no commercial value at the time and could not be sold, a considerable sum of money was realized, and for a time levee construction went on at a rapid rate. The levees, however, were of low grade and inferior construction, and consequently proved of little avail when tested by the great flood of 1858, which carried away the greater portion of the embankments north of the mouth of Red River.

At the outbreak of the civil war the levees in the Yazoo district were fairly continuous, but of too low grade to offer much protection, except during moderately high water, and by the time hostilities ceased there was little left to show that levees had ever existed.

The great flood of 1882, which inundated the entire delta, directed forcible attention to the necessity for united and organized effort toward controlling the flood waters. For the purpose of closing the many crevasses made by the flood of that year, an allotment of $1,300,000 was made from the funds appropriated by Congress in the River and Harbor Bill of that year for the improvement of the Mississippi River, which was the first allotment ever made by the Federal Government for levee purposes. Following this, small allotments were made for certain repairs in the levees made necessary by the succession of floods in 1883 and 1884. These allotments for repair of levees and subsequent allotments for construction and maintenance of levees were made by the Government for the purpose of improving the navigation of the stream, acting in accordance with the theory that the construction of levees would restrain the water in times of flood within a narrow space and that the additional force given by the weight of the water, together with the increased rate of flow, would tend to scour the channel and thus prevent the formation of sand bars by the deposit of sediment. This theory which led to the adoption of the plan for concentration of the waters of the river into one channel of an approximately uniform width, had been successfully applied in the opening and keeping open a deep channel through the South Pass of the Mississippi River from the head of the passes to the Gulf, and the success attained in that undertaking led to the belief that the same theory if applied to the entire river would deepen the channel.

[1] Riparian lands of the Mississippi River, (Tompkins), p. 140.

In support of his claim that the so-called "jetty system" could be applied to the river from the Gulf to the head waters, Captain Eads said:

> There can be no doubt of the entire feasibility of so correcting the Mississippi River from Cairo to the Gulf that a channel depth of 20 feet during low-water season can be permanently secured throughout its entire course, and the alluvial lands on each side of its waters can be made absolutely safe from overflow.

The first step taken was the creation of a permanent commission to be known as the Mississippi River Commission, and the act creating this commission became a law in June, 1879. This commission submitted a report in the year 1880, defining plans to be followed in the permanent improvement of the lower Mississippi River, the recommendations of which report were adopted by Congress as the project for the systematic improvement of the river

The Valley of the Mississippi is divided into a number of subordinate basins, each in a measure independent of the others, so that the task of protection against overflow is much simplified by reason of the fact that it did not necessarily require a vast and simultaneous organized effort or continuous levee system, but was one that could be undertaken in detail. Above the mouth of Red River there are four great basins, drained respectively by the St. Francis, the Yazoo, the Tensas Bayou, and Atchafalaya and their tributaries. All of these are now leveed, although the nearest approximation to a complete system has been made on the Yazoo front. The St. Francis Basin is a great oval plain with the Mississippi River from Cape Girardeau, Mo., forming its eastern boundary and a ridge of low hills, known in different places along the line as Hickory Ridge, Bloomfield Ridge, and Crowleys Ridge, forming its western one. Its greatest length is 218 miles, and it has an average width of 25 miles. From Commerce, Mo., to the lower end of the basin at Helena, Ark., the right bank is low, except at New Madrid, Mo. The upper portion of the St. Francis Basin is mostly hilly, while the lower and much larger portion is low and swampy with numerous lakes and bayous. This part of the basin slopes away from the river, and it also has a southern slope of 0.7 foot per mile. The basin is drained by the St. Francis River, which flows southward near the foot of Crowleys Ridge, and meets the Mississippi about 9 miles above Helena.

The Yazoo Basin is also an oval plain, and, like the St. Francis, slopes away from the Mississippi, a fortunate circumstance in connection with the construction of protection levees, as there are no streams emptying into the Mississippi for which openings were necessary. The eastern boundary of this great basin is a line of low hills along the base of which flows its principal drainage stream, known in its upper reach as the Coldwater River and toward its confluence with the Mississippi as the Yazoo. This stream is navigable for about 240 miles from its mouth.

The northern limit of the basin is near the Tennessee-Mississippi line. Here it is quite narrow, but farther south it widens out to a width of about 70 miles and then narrows again near the lower end at the mouth of the Yazoo. Its greatest length is 180 miles, and with the exception of a low ridge from 2 to 6 miles in width, an extension of Crowleys Ridge in Arkansas, which crosses the bottoms, the whole region is liable to overflow during times when the Mississippi is in flood.

The Tensas Basin extends from near the southern border of the St. Francis Basin to the mouth of Red River, its eastern boundary being the Mississippi River. The banks and the land generally are low and similar in character to those of the St. Francis and Yazoo basins, except that the Arkansas and White rivers find an outlet into the Mississippi, a fact which seriously interfered with levee construction.

The swamps in this basin are drained by Bayou Tensas, which unites with the Ouachita and Little rivers to form the Black, the most important tributary of the Red. The work of permanently closing this basin was commenced in 1888 and most of it was done after 1890. In 1897 the basin had been inclosed by a levee of an average height of 12 feet, but even then the flood overtopped the levee in many places, and several crevasses occurred. At the present time the levee in front of the Tensas Basin extends in an unbroken line from the high ground near Helena to the mouth of the Arkansas River and from near the mouth of the Arkansas to about 8 miles above the mouth of Red River.

Between Cape Girardeau, Mo., and Vicksburg there are five or six levee districts, organized under the laws of the various States, each with a separate board and corps of engineers, having control over the location and construction of levees along the front of the district, settling questions of rights of way, etc. The Federal Government, acting through the Mississippi River Commission, cooperates with the local levee authorities to some extent by alloting for levee work a portion of the funds appropriated by Congress for the general improvement of the river, which funds are expended in constructing on rights of way donated by the local levee boards, new levees where necessary to preserve the continuity of the line, in raising and enlarging old levees to a standard grade, and in assisting the local authorities in preserving the levees during flood periods.

The upper St. Francis levee district extends from the high lands at Commerce, Mo., to New Madrid, Mo., a distance of 85 miles. The levee is now built from about 20 miles above Cairo to about opposite Hickman, Ky., and though a line from that point to New Madrid has been proposed, the work is still held in abeyance on account of the difficulty in settling the question of drainage. In that section of the district several small rivers and bayous draining that portion of the State empty into the Mississippi and, until a means is provided for taking care of the surface water, this stretch of about 30 miles will remain

open. On the left bank of the river a line of levees now runs from Hickman, Ky., to the foot of Donaldsons Point, which is about opposite Point Pleasant, Mo., the northern end of the lower St. Francis levee system. The purpose of this levee is to restrain the overflow water from passing into Reelfoot Bottom and flooding Lake County, Tenn., and other sections in that vicinity.

The lower St. Francis levee district extends from Point Pleasant, Mo., to Helena, Ark. Formerly when the Mississippi between Cairo and Memphis reached a stage of 25 or 30 feet, the water would spill over the low banks and back up the numerous bayous until the swamps and low places were filled. Then as the river rose still higher, the surplus water would flow uninterruptedly over the land to the westward and enter the St. Francis River through which it found its way to the main stream at Helena. The purpose then of the St. Francis levee is to compel the flood waters in the Mississippi River to follow their natural channel instead of flowing out over the land. Levee construction in the lower St. Francis district began soon after 1850. and by 1858 a somewhat broken line of embankments extended from the high lands below New Madrid, Mo., to near the lower end of the basin. These, however, as before stated, were of little avail against floods and most of them were soon destroyed. Nothing further was done toward an organized movement to close the basin until 1893, when the first St. Francis Levee Board was formed, and the Government began to make yearly allotments for levee work. When the great flood of 1897 occurred the St. Francis levee only extended as far south as Pecan Point, a distance by river of about 125 miles. This line was made up principally of the old State levee above referred to, which had been enlarged and strengthened, but when put to test by the flood was found too small and upon the whole quite inadequate to effect the object intended. While this levee in a measure resisted the ravages of the flood in some places, there were 23 serious breaks in 1897, mostly in the lower portion of the line, and as a result the country received very little protection. Six years later, in 1903, this line of levee had been extended southward as far as Cat Island, below Memphis, a total length of 173 miles. The whole line had been practically rebuilt when the flood of 1903 occurred and in that year there were only two breaks, notwithstanding that the water was much higher than in 1897.

The present length of the lower St. Francis levee line is 202.5 miles, which added to the upper St. Francis line, comprising 47.5 miles, gives a total of 250 miles of levee on the right bank of the river above Helena. Below Helena on the right bank of the river, the White River district has 74 miles, upper Tensas 190.6 miles, lower Tensas 153 miles, a total of 417.6 miles, which added to the 250 miles in the St. Francis system gives a total of 667.6 miles of levee on the right bank above the mouth of Red River.

The St. Francis levee has an average height of 16 feet, with a base 104 feet and a crown 8 feet in width, topped by a curved section with a 3-foot crown. The levee of course varies in dimensions according to the level of the location upon which it is built, but it is believed to be sufficient to hold a volume of water equal to that of 1882. The work already done in this district alone has cost the people of the St. Francis Basin $2,500,000, in addition to about $2,000,000 allotted by the Federal Government. The work yet to be done in order to bring the St. Francis levee system to the ideal proportions will probably increase the total expenditure to near $7,000,000. The great value of this levee to the country will be the reclaiming of 2,240,000 acres of the richest and most productive soil in the world.

The Yazoo Levee Board was organized in 1884. At that date the levees were insignificant, both in height and other dimensions and of very inferior construction as compared to present levees. They had been long neglected and in some places there was little to distinguish them from the natural ground. They could therefore afford little or no protection against a flood. The upper Yazoo levee district covers a distance of 124 miles and extends from the northern line of the State of Mississippi, near Horn Lake, to the southern boundary line of Bolivar County. The lower Yazoo district extends from the Bolivar County line to near the mouth of Yazoo River, a distance by river of about 230 miles. The length of this line of levees is 188 miles, making in all 312 miles of levee in the State of Mississippi. These levees are practically complete and are considered sufficient to withstand the highest water.

In 1882 the lower Yazoo levee line was very irregular in grade, with an average height of only about 7 feet and broken by extensive gaps. In that year or immediately following the great floods of 1882 and 1883, the real work of constructing a levee on something approaching modern lines began, and the work progressed so well that in 1884 there was but one crevasse in the entire line. After this no break occurred in the lower Yazoo district until 1890, when there were six, and again in 1891 when one break occurred. In 1897 occurred the greatest overflow ever experienced in the lower valley; the levee in this district broke in five places, and one very serious crevasse occurred in the upper district, making six in all. In 1903 one break occurred in the lower district, but since that year the levees have withstood all floods.

On July 1, 1908, there were 1,486 miles of levee along the river south of Cape Girardeau, Mo., not including those on the tributary streams. Since that time some extensions have been made and many miles of new levee constructed to replace those that were located too near the river, or upon unstable foundations. One of the many serious problems confronting the levee builder is that of caving banks. These encroachments of the river, which most often take place in the bends, frequently bring about changes in the course of the river and annually destroy many

miles of expensive levees which must be replaced by new ones built farther back from the river. In certain of the bends of the river as many as five lines of levee have been built in the past thirty years and as long as these conditions exist, a strictly permanent levee system is impossible. Again, the ever-increasing elevation of the flood planes, due to additional constrictions of the flood volume by the extension of new lines of levees, renders the establishment of permanent levee grades extremely difficult, if not impossible, until they are brought to an actual test under the newly-developed conditions. The flood of 1897 found the river in the Yazoo district leveed on both sides for the first time in history, and the effect of this was a filling of the depressions, the establishment of a new flood plane in accordance with the changed conditions, and a disturbance of gage relations at all points above Helena. In this way, new grades that have been established at various points in the St. Francis system, in accordance with the changed conditions due to the presence of levees on the left bank of the river, have raised the flood plane above the original estimates, and as a result a vast amount of enlargement work has been required. These enlargements and the building of new loops around badly-constructed or improperly-located levees constitute the principal work at the present time.

The total amount expended by the Federal Government on levee work below Cairo to July, 1908, was something over $23,000,000, and, while the amount expended by the different States is not known, it is supposed to have been in the neighborhood of $30,000,000. The area protected by these levee systems is approximately 27,000 square miles or about 17,300,000 acres.

EFFECT OF LEVEES ON FLOOD STAGES.

In former times the effects of a rise in the river upon the swamp lands began to appear when the rising water attained the level of the bed of the connecting bayous, that is, when the surface of the river was still 10 or 15 feet below the top of the natural banks. The first effect was to stop the discharge of these bayous and to accumulate rainwater in the swamps. As the Mississippi rose to still higher levels a considerable volume of water was poured into the bottoms through the numerous bayous and other outlet streams, and as a result the swamps and low places were often well filled before the river even reached a bank-full stage.

Since the levees, as now constructed, close these bayous and exclude the Mississippi water from the swamps, their effect on the river become apparent to some small extent with stages as low as 25 feet, becoming more and more pronounced as higher levels are reached. The ground usually being higher near the edge of the bank than at the base of the levee, a flood which only partially covers the ground in the vicinity of the bank, often puts several feet of water against a levee that has been

built some distance back from the river, while one built on the immediate bank is entirely free from water.

It is probable that the levees constructed previous to 1871 from Cape Girardeau to Vicksburg had the effect of increasing the height of the flood plane in certain reaches of the river, but, owing to the lack of continuity in the line of levees and the absence of comparable stage data, it is not possible to even approximate the changes in the river regimen until a much later date.

In 1871 river gages were established at several places along the river and daily observations of the height of the river became a part of the duties of the Weather Bureau observers at all river stations. This was the beginning of a systematic daily survey of the river fluctuations that has continued without change or interruption to the present time. The Mississippi River Commission was created in 1879, and soon thereafter the course of the Mississippi was accurately surveyed and its slope determined by precise levels. Additional river gages were also established at that time, so that since 1880 the daily stages have been recorded at intervals of about 50 miles or less along the entire course to New Orleans.

The zero point on the Mississippi River gages usually represents the lowest level the surface of the water had reached at the time the gage was established, but in many instances the water has since gone below this mark. The elevations of gage zeros are referred to the mean Gulf level at Biloxi, Miss. That is, the elevation of the zero of the gage at Cairo is 270.9 feet above mean Gulf level, Memphis, 184.1 feet, Helena, 142.1 feet, Greenville, 88.5 feet, Vicksburg, 46.2 feet, Natchez, 17.1 feet. Thus the zero elevations of the various gages give approximately the low-water plane of the river. An approximate relationship exists between the gage readings on the Mississippi when normal stages prevail, and if the natural banks were sufficient to hold all the water that passes Cairo this relationship would be fairly constant, except when disturbed by heavy discharges from tributary streams. But, through the overflowing of banks and the consequent loss of water to the swamps, the crest of a rise loses its identity and the relation between the gages is seriously disturbed. The occurrence of a crevasse at any point in the line of levees has the same effect on all gages located between the point of the break and the foot of the basin.

Since 1882 the conditions affecting the flood regimen in this reach of the river have materially changed by the extension and enlargement of the levees, and during the twenty years ending with the year 1903, they have undergone an annual change so that rules established in one flood year could not be successfully applied to the one following, no two being exactly alike. However, with stages of 30 feet or under at Cairo the relation between the gages is probably very near what it was in 1871; in fact, the records show very little change.

Levees have no marked effect on river stages, except when the river is out of its banks or rises sufficiently high to cause a considerable amount of water to back up the tributary streams where such exist. In this reach of the river (Memphis) there is very little loss of water unless the river reaches a stage of about 25 feet at Memphis.

As all great floods emanate north of Cairo the gage at that place is accepted as an index to what will follow at points below.

The difference between Cairo and Memphis, with Cairo reading 20 feet or less, is from 5 to 7 feet and for stages up to 30 feet at Cairo the difference is approximately 7 feet, Cairo reading the higher. These were the gage relations in 1872 and they are practically unchanged at the present time. Previous to 1896 when the water during flood periods was unrestrained by artificial embankments, the difference between Cairo and Memphis increased in proportion to the height of the flood wave, while under the changed conditions south of Cairo, the tendency during extreme high water is for the two gages to come closer together. Formerly a 46-foot stage at Cairo gave Memphis 35 feet, which was the maximum at the latter place up to 1897, when the levees first began to show their effect. The highest stage on record at Cairo is 52.3 feet, which occurred in 1883, and the resultant stage at Memphis was 35 feet, or the same as is now shown by a 46-foot stage. This indicates that there was a loss due to overflow water passing into the bottom lands of about 7 feet. The difference between Cairo and Memphis in 1882, 1883, and 1884, when the stage at Cairo reached the extreme height of 52 feet, was 17.5 feet. In 1897, with an imperfect levee fronting only about one-third of the St. Francis Basin, the difference was reduced 3 feet. In 1903, with a still incomplete levee and two serious breaks a few miles above Memphis, the difference was only 10.6 feet, a reduction since 1897 of about 4 feet, and since 1884 of about 7 feet. In 1907, by reason of the further extension and enlargement of the St. Francis system of levees, a further increase in the flood level at Memphis is shown. In that year the difference between the Cairo and Memphis gages was exactly 10 feet, showing that the flood plane at Memphis had been raised 7.6 feet since 1884, and that this increase was brought about by confining the water to narrower limits through the extention of the Arkansas levee along the right bank of the stream. It should be borne in mind that notwithstanding the abnormal stages below Cairo in 1903 and 1907, the actual volume of water coming into the valley was much less than in either 1882 or 1884 and decidedly less than in 1897. Not only was the stage at Cairo 1 foot below the record for the years named, but the wave was much shorter. At Cairo in 1882 the water was above a 40- foot stage on 81 days, above 45 feet on 56 days, and above 50 feet on 9 days. In 1907 it was above these stages on 34, 16, and 4 days, respectively.

Since 1907 a line of levees has been constructed in Scott County, Mo., om the high ground at Commerce, Mo., to the west end of Big Lake,

about 15 miles west of Cairo, where it joins the Mississippi County levee and forms a continuous line to below Island No. 5. The closing of this reach of 15 miles will, in times of overflow, prevent the water from flowing out over Scott County, Mo., to the tributaries of the White and the St. Francis rivers, by which they were formerly carried southward to join the main stream at Helena and below. Another factor having a material effect on the gages at New Madrid and Memphis is the new line of levees on the left bank running from Hickman, Ky., southward to near Tiptonville, Tenn., but as this levee has not yet been built to the standard grade, its effect during extreme high water is uncertain. As the highest water that has occurred since 1907 is over 5 feet below the extreme stage, it is difficult if not impossible to accurately determine the final effect of these recent levee extensions on the river below Cairo, but at the highest stage in 1909, 47.3 feet at Cairo, an increase in the flood plane is noted at both New Madrid and Memphis. The increase at New Madrid certainly amounts to 2 feet, while at Memphis it is probably somewhat less. It is reasonably certain, however, that a flood equal to those of 1883 or 1884 would give Memphis at least 43, and possibly 44 feet, provided there were no breaks in any of the levees. Table 1 gives the maximum stages at different points along the river during the three great floods that have occurred since 1882, and also during the year 1909, and shows the changes in the gage relations to the present time; also the expectations regarding future floods based on the water of 1882:

TABLE 1.

Stations.	1882.		1897.		1903.		1907.		1909.		Expectation based on 1882.
Cairo	51.8		51.6		50.6		50.4		47.3		
New Madrid	41.5	−10.3	40.3	−11.3	39.5	−11.1	39.3	−11.1	38.6	− 8.7	44.0
Fulton	36.7	−15.1	37.5	−14.1	40.2	−10.4	38.4	−12.0	35.5	−11.8	41.0
Memphis	35.2	−16.6	37.1	−14.5	40.1	−10.5	40.3	−10.1	38.6	− 8.7	43.5
Helena	47.2	− 4.6	51.8	+ 0.2	51.0	+ 0.4	50.4	± 0.0	47.7	+ 0.4	52.0
Arkansas City	47.0	− 4.8	51.9	+ 0.3	53.0	+ 2.4	52.1	+ 1.7	50.1	+ 2.8	55.0
Greenville	41.7	−10.1	46.8	− 4.8	49.1	− 1.5	47.3	− 3.1	44.8	− 2.5	51.0
Lake Providence	38.3	−13.5	44.5	− 7.1	46.5	− 4.1	46.3	− 4.1	44.4	− 2.9	48.0

All changes are computed from the maximum stages at Cairo.

The estimates here made are based on data taken from the early spring rises only. At such times the ground is well saturated and the swamps and tributary streams more or less full of water, and as a result a flood wave coming into the valley produces its maximum effect. Later in the spring or during the early summer months, with a deficient moisture supply in the ground, and with the streams low, a given stage at Cairo will give lower resultant stages at all points below. Again, the crest stage is affected to a considerable extent by the condition of the White and Arkansas rivers. This is particularly noticeable at Helena and Arkansas City. With those rivers in flood, or when the

lower Mississippi is abnormally high, the slope is somewhat decreased and consequently the run-off is checked to an extent sufficient to cause the Helena gage to show a higher stage with reference to Cairo than would be the case if the lower rivers were low and the slope normal. Under the latter condition it is possible for a 45-foot stage at Cairo to give 35 feet at Memphis and 44 feet at Helena, and corresponding stages at points below. However, under favorable flood conditions, the Memphis gage will show from 8.5 feet to 9.5 feet less than Cairo on stages exceeding 40 feet at the latter station. The difference between Cairo and Helena for stages under 35 feet is about 1.5 feet, that is Helena will be that much below Cairo, while the difference at Memphis is from 7.5 to 8 feet.

EFFECT OF LEVEES ON THE RIVER SOUTH OF MEMPHIS.

Helena, Ark., being located at the lower end of the St. Francis Basin, the gage at that place was formerly affected to a considerable extent by the return flow of the waters that had escaped from the main stream between Cairo and Memphis. It has been estimated that this return flow, which usually occurred about the time the flood crest reached Helena, had the effect of raising the stage at that place about 3 feet. That it prolonged the flood at Helena there is no room for doubt, as will be seen in another portion of this report. Mr. H. N. Pharr, Chief Engineer of the St. Francis Levee Board states in this connection as follows:

> The return flow from the St. Francis Basin at Helena has the effect of raising the water on that gage at least 3 feet above what it would do if the basin had been closed. An idea of the quantity of support given the flood in the lower river may be had when it is stated that the area of the St. Francis Basin is about 5,000 square miles and the average depth is about 8 feet. Supposing the basin to be filled, as sometimes was the case, this water would equal a stream one mile wide, 1,000 miles long, and 40 feet deep. Flowing at the rate of 1,000,000 cubic feet per second, or an average velocity of 4.5 feet per second, it would take 14.5 days to run out. This is close to what, in fact, occurs.

The idea of building the St. Francis levee until those below were perfected, was strongly opposed by property owners along the lower river, the objection being based on the supposition that closing the basin would raise the flood height at Helena and from there southward to the Gulf. Engineers, at least many of them, held to the opposite opinion, and some went so far as to say it would lower the flood at Helena and possibly at points below.

Colonel Suter of the United States Engineer Corps gave it as his opinion that—

> In a general way it has been shown that the large increase in the flood height has been mainly confined to intermediate points along the great swamp basins. At the lower end of these basins the change has been slight, as for instance, Vicksburg. The only feature of the uncertainty which now remains is the effect of leveeing the St.

Francis Basin. That will increase the flood height at Memphis and all points above seems certain, but so far as concerns the river below Helena there is much to be said. All the water which now reaches the main stream above the junction with the White River now passes Helena between levees, and hence has produced its maximum effect.

During the great floods of 1882, 1883, and 1884, the maximum stages at Helena and their relations to the Cairo gage were substantially the same, that is to say, Helena had 47 feet against 52 at Cairo, a difference of 5 feet. At that time there were no levees on the Arkansas side of the river, and those on the left bank were not sufficient to hold the water at flood stage. By 1886, however, the Mississippi state levee had been enlarged; the crevasses that were made during the great floods that occurred after 1882 were all closed, and, although the river reached a stage of 48.1 feet, no break occurred. This was 1 foot higher than ever before known at Helena, notwithstanding the fact that Cairo was 1 foot below its maximum. This would indicate that the levee was responsible for an increase in the flood height of 2 feet.

The next extreme high water occurred in 1897, and at that time there was a good, strong levee on both sides of the river in the vicinity of Helena, but otherwise the conditions were about the same as when the floods above mentioned occurred. The maximum stage at Helena was 51.8 feet, or nearly 5 feet above the previous record, while Cairo was still a fraction of a foot below the extreme flood stage. A higher maximum would probably have been shown had it not been for the great Flower Lake crevasse, which occurred on the opposite side of the river, a few miles above Helena on April 3, and diverted an immense body of water to the swamps of Mississippi. At the time the crevasse occurred the river was rising steadily at the rate of three or four-tenths of a foot daily, so it is reasonable to suppose that, if the levee had held, Helena would have experienced a stage exceeding 52 feet. At this time the St. Francis Basin was only leveed from Point Pleasant, Mo., to Pecan Point, Ark., and even that offered but little resistance to the flood.

In 1903 the St. Francis levee extended only to Cat Island, a few miles below Memphis, and from there to the foot of the basin there was no levee protection whatever. In addition to this there were two serious crevasses a few miles above Memphis, so that the lower portion of the basin was about as deeply flooded as in former years when there were no levees at all. This being the case the gage relation between Cairo and Helena that obtained in 1897, was not disturbed, both recording practically the same stage.

The first real test regarding the effect at Helena came in 1903. The St. Francis levee system was complete from the high ground in Missouri to the mouth of the St. Francis River and the whole line, both above and below Helena, was intact. Referring to Table 1 it is seen that Helena still follows Cairo very closely, and the two gages have the same relation to each other as in 1897 and 1903. Thus the contention that the St.

Francis levee would not raise the flood level at Helena is to some extent verified. The fact remains, however, that there is a fairly permanent ratio of unity between Cairo and Helena at an overflow stage, and the contention of some eminent engineers that the extreme maximum at Helena would not exceed 49 feet does not appear to be well founded. That the St. Francis levee did not raise the flood level at Helena is due to the fact that the return flow from the basin has been eliminated and this offsets whatever effect the restraint offered by the levee may have had.

While the complete closing of the St. Francis Basin has had the effect of giving increased stages at all intermediate points it is seen by Table 2 that it has also had the effect of materially shortening the duration of the floods at Memphis and Helena as well as at some points below:

TABLE 2.—*Number of days above flood stage.*

Year.	Cairo.	Memphis.		Helena.		Arkansas City.	Greenville.	Lake Providence.	Vicksburg.
	45 feet.	33 feet.	35 feet.	42 feet.	45 feet.	42 feet.	42 feet.	42 feet.	45 feet.
1882.....	56	65	6	79	48	108	0	0	39
1890.....	43	41	35	28	32	112	40	0	95
1897.....	47	55	45	66	48	72	45	42	70
1903.....	20	43	23	65	29	81	39	27	60
1907.....	16	30	16	33	19	59	31	29	33

At Memphis the river was above flood stage (33 feet) on 55 consecutive days in 1897, 43 days in 1903, and 30 days in 1907. At Helena it was above flood stage (42 feet) on 66 days in 1897, 65 days in 1903, and 33 days in 1907. In 1897 Cairo was above flood stage (45 feet) on 47 days, and above 50 feet on 15 days. In 1907 it was above 45 feet on 16 days, and above 50 feet on 4 days. It is true the volume of water in 1907 was not equal to that of 1897, but the difference in volume is not sufficient to account for the great decrease in the length of the flood period at Helena, that is, from 66 to 33 days. At Memphis the effect of the river as regards the run-off is not as noticeable as at Helena, but it is believed the flood period has been shortened at the former place, as shown by the rapidity of the fall in 1904 and 1907, as compared with previous floods. In 1907 it was not until 43 days after the arrival of the crest that the water fell below flood stage, while in 1904 it took only 10 days, and in 1907 only 9 days.

As floods in the lower Mississippi River usually occur during the planting season, the importance of hastening the withdrawal of the water from the land can not be overestimated. A difference of a few days may sometimes determine the fate of a crop. There are large tracts of rich tillable land lying unprotected along both banks of the river, as well as numerous island plantations that are more or less flooded each year. These overflows are expected, and, as a rule, are of great benefit to the

soil, as they leave a rich deposit on the land. The levees have caused these lands to be more extensively and more deeply flooded and in some individual cases have worked a distinct hardship to the people occupying them. At the same time, if the period of inundation is materially shortened by confining the river to its natural limits, this hardship is greatly mitigated, and, on the whole, the levees may prove a benefit even to the lands that have no protecting levee.

Below Helena the gage readings show an increase in flood planes from 1882 up to the present time. These changes are very pronounced at all intermediate points along the Yazoo and upper Tensas fronts, and the least noticeable at Vicksburg, which is located at the bottom of the basin. The greatest increases in the flood plane are seen at Lake Providence, La., Greenville, Miss., and Arkansas City, Ark., respectively. In 1883 Greenville was 11.8 feet below the Cairo gage, but in 1903 the difference had been reduced to 1.6 feet, an increase in the flood plane of 10.2 feet. At Lake Providence the effect of levee construction on the flood waters is even more pronounced, the increase at that place amounting to 12 feet. At Arkansas City, previous to 1897, the flood crest was usually about 5 feet below the Cairo reading, but in 1903 it was 2.2 feet above, an increase of about 7 feet since 1890.

The abnormal stage at Greenville in 1903 and the remarkable change in the gage relation between Greenville and Arkansas City has been extensively discussed by engineers and others, and various theories have been advanced as to the cause. When the levees were small they were built so as to follow very closely around the bends and points because the highest ground was usually found close to the river bank, and on many of the points the bank was so high that up to 1882 levees were unnecessary. Then the points were practically leveed in. This had the effect of causing the high-water channel to conform closely to the low-water channel. As the different basins on each side of the river began to be leveed and closed up, the high-water level rose higher and higher, making it necessary to increase the height of the levee. As this work is very expensive and the value of the land on the points is not always in proportion to the cost of maintaining a high grade levee, it was often found expedient to shorten the length of the levee line by building new levees across the necks and throwing out the long lines around the points. This was done in that crooked reach of the river extending from Catfish Point, which is about 10 miles by river above Arkansas City, to Leland, just below Greenville. The distance along the channel of the river is about 48 miles, but in a direct line it is only 10 or 12 miles. The old levee following closely around the bends was about 53 miles in length. This was replaced by one running in a more direct line and disregarding the bends, so that a saving was made of about 42 miles of levee. The effect of throwing out the old levees around the bends is to give the flood water free sweep across the points instead of following

around the channel of the river as formerly, the same as though a series of cut-offs had been made in the bends above Greenville, thereby giving a greater slope to the water and consequently a greater velocity.

The writer believes that the abnormal height at Greenville in 1903 was due in part to the fact that the levees on each side of the river converge a few miles below Greenville, so that the distance between them is only about 1½ miles. This holds the water back and produces an effect similar to that which would be caused by a dam. At Arkansas City the distance between the Mississippi and Arkansas levees is 5 or 6 miles, and below the gage the distance ranges from 10 to 15 miles. It is probable that the increased slope and consequent increased velocity given the overflow water in passing across the points, as above explained, throws a larger volume of water into the narrow space between the converged levees below Greenville than would be possible if the water had followed the natural channel of the river. The average difference in slope between Arkansas City and Greenville, comparing maximum gage readings for the years 1884, 1887, 1891, and 1898, is 5.32 feet. At the highest stage reached in 1903 the difference was only 3.9 feet, showing an abnormal rise at Greenville of 1.4 feet..

TABLE 3.—*Extreme stages during four recent floods in the Mississippi River compared to 1882.*

	1882.	1897.		1903.		1904.		1907.	
Cairo	51.8	51.6	−0.2	50.6	−1.2	49.1	−2.7	50.4	−1.4
New Madrid	41.5	40.3	−1.2	39.5	−2.0	37.5	−4.0	39.3	−2.2
Fulton	36.7	37.5	+0.8	40.2	+3.5	37.4	+0.7	38.4	+1.7
Memphis	35.2	37.1	+1.9	40.1	+4.9	39.0	+3.8	40.3	+5.1
Mhoons	39.8	41.6	+1.8	41.8	+2.0	40.3	+0.5	42.2	+2.4
Helena	47.2	51.8	+4.6	51.0	+3.8	47.7	+0.5	50.4	+3.2
White River	48.4	52.4	+4.0	53.7	+5.3	49.5	+1.1	51.9	+3.5
Arkansas City	47.0	51.9	+4.9	53.0	+6.0	49.0	+2.0	52.1	+5.1
Greenville	41.7	46.8	+5.1	49.1	+7.4	43.5	+1.8	47.3	+5.6
Lake Providence	38.3	44.5	+6.2	46.5	+8.2	42.5	+4.2	46.3	+8.0
Vicksburg	48.8	52.3	+3.5	51.8	+3.0	46.9	−1.9	49.7	+0.9
Natchez	47.8	49.8	+2.0	50.4	+2.6	45.6	−2.2	48.9	+1.1

TABLE 4.—*Annual maximum river stages.*

Year.	Cairo.			Memphis.			Helena.			Arkansas City.			Greenville.			Lake Providence.			Vicksburg.		
1872	39.2	Apr.	19	31.5	Apr.	24	39.0	Apr.	26							35.2	May	1	39.5	May	2
1873	41.6	Feb.	26	32.5	Mar.	3	40.0	Mar.	6							36.1	May	27	40.6	May	29
1874	47.4	Apr.	26	34.0	May	2	45.8	May	11							37.4	Mar.	20	45.7	May	2
1875	45.1	Aug.	7	33.0	Aug.	15	42.4	Apr.	12							37.3	Apr.	19	43.0	Apr.	21
1876	46.4	Apr.	6	34.1	Apr.	8	44.8	Apr.	17							38.0	Apr.	12	44.9	May	10
1877	40.5	Apr.	15	32.0	Apr.	29	41.8	Apr.	30							35.8	May	4	41.6	May	8
1878	37.0	Apr.	29	29.1	May	2	38.8	May	3							35.8	Mar.	22	41.0	Mar.	24
1879	36.5	Dec.	31	28.1	Jan.	29	37.2	Jan.	31							36.0	Feb.	14	39.4	Feb.	16
1880	44.6	Mar.	22	33.4	Mar.	23	43.8	Mar.	31	45.1	Mar.	21				38.0	Apr.	3	43.2	Apr.	8
1881	45.8	Apr.	19	33.3	Apr.	27	43.7	May	13	44.3	May	17				36.2	Mar.	8	41.8	Mar	9
1882	51.8	Feb.	25	35.2	Mar.	6	47.2	Mar.	9	47.0	Feb.	28	41.7	Feb.	27	38.3	Mar.	20	48.8	Mar.	20
1883	52.2	Feb.	27	34.8	Mar.	6	46.9	Mar.	8	46.3	Mar.	11	40.4	Mar.	10	36.5	Mar.	11	43.8	Apr.	7
1884	51.8	Feb.	21	34.2	Mar.	1	47.0	Mar.	6	46.5	Mar.	7	41.1	Mar.	8	38.4	Mar.	23	49.0	Mar.	25
1885	39.0	Jan.	26	29.3	Jan.	28	40.7	Jan.	30	42.6	May	8	38.0	May	7	35.5	May	10	42.4	Feb.	3
1886	51.0	Apr.	18	34.8	Apr.	22	48.1	Apr.	30	46.9	May	5	41.2	May	6	37.9	May	6	44.2	May	7
1887	48.5	Mar.	9	35.3	Mar.	9	46.3	Mar.	21	46.6	Mar.	23	40.8	Mar.	21	38.0	Mar.	26	44.7	Mar.	26
1888	45.2	Apr.	3	34.2	Apr.	11	42.8	Apr.	14	45.4	Apr.	22	40.6	Apr.	22	38.1	Apr.	24	44.2	Apr.	26
1889	34.5	June	24	26.6	June	27	34.1	June	28	36.2	June	30	31.8	July	1	29.4	July	1	34.4	July	3
1890	48.8	Mar.	12	35.6	Mar.	15	47.7	Mar.	29	49.3	Mar.	27	43.4	Mar.	17	41.0	Mar.	15	49.1	Apr.	25
1891	46.2	Mar.	4	34.9	Mar.	10	44.7	Mar.	26	48.2	Apr.	4	43.2	Apr.	1	41.0	Mar.	31	48.1	Apr.	2
1892	48.2	Apr.	27	34.6	May	2	45.8	May	11	49.9	June	1	44.5	June	1	41.9	June	2	48.4	June	*2
1893	49.3	May	9	35.2	May	15	48.0	May	25	50.3	May	29	44.3	May	29	41.8	May	15	48.3	May	22
1894	37.0	Feb	16	29.4	Feb.	20	38.0	Feb.	21	40.5	Feb.	24†	35.4	Feb.	25	34.3	Mar.	30	40.9	Apr.	2
1895	33.3	Mar.	25	24.0	Jan.	24†	31.2	Mar.	30	32.5	Apr.	1	27.7	Apr.	2	25.9	Apr.	2	31.7	Apr.	4
1896	39.2	Apr.	13	29.5	Apr.	16	38.4	Apr.	17	40.1	Apr.	19	34.6	Apr.	20	33.2	Apr.	20	39.0	Apr.	21
1897	51.6	Mar.	25	37.1	Mar.	19	51.8	Apr.	4	51.9	Mar.	29	46.8	Mar.	29	44.5	Mar.	30	52.3	Apr.	16
1898	49.8	Apr.	6	37.3	Apr.	11	49.1	Apr.	17	51.2	Apr.	19	46.2	Apr.	21	44.4	Apr.	23	49.4	Apr.	24
1899	46.2	Mar.	30	35.3	Mar.	30	46.9	Apr.	10	48.6	Apr.	15	43.0	Apr.	17	41.6	Apr.	16	47.3	Apr.	16
1900	39.2	Mar.	17	29.5	Mar.	19	38.1	Mar.	21	39.3	Mar.	25	33.7	Mar.	25	33.0	Mar.	25	38.0	Mar.	27
1901	43.2	May	2	32.1	May	6	41.6	May	9	43.3	May	12	37.4	May	13	36.4	May	14	41.5	May	15
1902	42.2	Mar.	17	30.8	Mar.	20	39.6	Mar.	23	41.4	Mar.	28	36.0	Mar.	29	35.0	Apr.	16‡	41.2	Apr.	17
1903	50.6	Mar.	15	40.1	Mar.	20	51.0	Mar.	25	53.0	Mar.	27	49.1	Mar.	27	46.5	Mar.	27	51.8	Mar.	27
1904	49.1	Apr.	5	39.0	Apr.	10	47.7	Apr.	15	49.0	Apr.	19	43.5	Apr.	20	42.5	Apr.	21	46.9	Apr.	24
1905	38.6	May	24	29.0	Mar.	21	37.8	May	29	43.2	June	3	36.8	June	3	36.5	June	4	40.8	June	6
1906	46.9	Apr.	9	37.0	Apr.	16	47.0	Apr.	18	50.0	Apr.	22	44.9	Apr.	23	43.7	Apr.	23	47.2	Apr.	26
1907	50.4	Jan.	27	40.3	Feb.	3	50.4	Feb.	5	52.1	Feb.	8	47.3	Feb.	8	46.3	Feb.	9	49.7	Feb.	11
1908	45.6	Mar.	18	35.6	Mar.	23	45.2	Mar.	26	49.9	June	2	44.7	June	2	44.1	June	5	47.9	June	6
1909	47.3	Mar.	17	38.6	Mar.	22	47.7	Mar.	25	50.1	Mar.	28	44.8	Mar.	29	44.4	Mar.	30	48.1	Apr.	2
Extreme	52.2			40.3			51.8			53.0			49.1			46.5			52.3		

NOTE.—Where the maximum occurred on more than one date the first only is given. *Also on May 10. †Also on March 29. ‡Also on March 30.

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